Transaction to Carbon (TtC)

An open standard framework for consumer carbon calculations based on payment transactions.

EEIO hybrid methodology





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About OfCC (Organization for Conscious Consumerism)

As a non-profit organization, we envision enabling the development of an impact economy driven by conscious consumerism. Our mission is to accelerate the adoption of conscious consumerism through behavioural change incentives and sustainability data transparency, leading to positive social, economic, and environmental impacts. Our data- and technology-driven concepts aim to bring new insights into the process, from individual consumption behaviours shifts in systemic change. to The open standards, methodologies, and data concepts we establish, in collaboration with our scientific and industry partners, serve the common good of our society. We are an independent non-profit organization owned by ecolytiq GmbH, Berlin.

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1.Introduction

As the world enters a new decade of this still young millennium, sustainability has become an overarching goal for individuals and humankind. New ideas and approaches to ensure each person, corporation, and political unit can contribute to a more liveable world emerge daily. In seeking to make such a contribution to our collective future, innovation in one of the most established aspects of our economy and society: personal finance and consumption, has also gained momentum in recent years. Evidence by the proliferation of FinTech firms specializing in many niche areas, such as green payments, ESG investments and carbon accounting.

Transforming consumption behaviour via intervention in personal finance requires leveraging data and technology. The tools developed to link carbon emissions to monetary units enable consumers to visualize the impact of their consumption. Analyzing individual consumption patterns based on financial transactions and linking the said transactions with carbon emissions creates transparency about one's carbon footprint. Financial institutions play a crucial role in turning this knowledge into actionable content for consumers, giving them the power to understand and take control of their environmental impact.

In 2021, we introduced the Open Standard Framework for Consumer Carbon Calculations (Lanza et al., 2023), which has been continuously reviewed and improved since then. This white paper describes the fundamentals of the EEIO Hybrid methodology to estimate the carbon intensity factors, measured in CO2e per monetary unit used by ecolytiq GmbH. As outlined in the Open Standard, the EEIO hybrid methodology is based on publicly available/licensed Global Multiregional Input-Output tables such as the EXIOBASE 3 (Stadler et al., 2021a), OECD ICIO (OECD.Stat, 2022), GTAP10 (Purdue University, 2019), WIOD (Dietzenbacher et al., 2013), Eora (KGM & Associates Pty. Ltd., 2023), Figaro (Remond-Tiedrez & Rueda-Cantuche, 2019), Gloria (Lenzen, 2023). Emissions factors from this GMRIO then need to be allocated to the Classification of individual consumption by Purpose (COICOP) (UN, 2018).

This whitepaper aims to promote standardization and self-regulation when calculating carbon intensity factors using the EEIO hybrid approach. Like the Open Standard, this document seeks to set the discussions around methodologies and initiate collaborations across the financial sector and sustainability-minded businesses.

This document is structured as follows: section 2 presents the rationale of the methodology; section 3, the methodology. Section 4 offers the limitations, followed by conclusions (Section 5) and further resources (Section 6).





2. The rationale for the methodology

The consumption-based approach to carbon accounting differs from the traditional, production-based inventories because imports and exports of goods and services, directly or indirectly, involve CO₂ emissions (Davis & Caldeira, 2010). In today's global economy, emissions embedded in trade makes a significant share of the country's emission, and therefore the traditional approach largely underestimates the emissions. Consumption-based accounting considers the CO₂ emitted in producing goods elsewhere, which are later imported, or emissions from exported goods. This approach links local consumption and global environmental consequences (Ivanova et al., 2017).

2.1 Environmentally extended input-output approach

The environmentally extended input-output (EEIO) expands the traditional Input-Output (IO) analysis. The IO analysis examines the interdependencies between different sectors of an economy by tracking the flow of goods and services between them. Incorporating the environmental impacts associated with economic activities provides a detailed picture of an economy's production and consumption activities. Therefore, EEIO is an excellent tool for consumption-based accounting of CO₂ emissions. The EEIO analysis varies in scope and level of detail based on the IO tables used. Some of the most common types of IO tables are the Single Region Input-Output (SRIO), Multi-Regional Input-Output (MRIO) and Hybrid Input-Output tables. The SRIO focuses on the economic interdependencies within a single geographic region or economy where the interactions between different sectors or industries within an economy are captured. The MRIO captures the transactions between sectors within each region and the trade flows between regions or countries, each represented by its own set of sectors and IO tables. Hybrid input-output tables are similar to SRIO tables but combine monetary and physical units and incorporate elements of life cycle assessment and process analysis.

2.2 Integrating top-down and bottom-up emissions accounting approaches

The Environmentally Extended, Input-Output tables provide a consistent framework for allocating environmental burdens from the overall emissions and resource consumption generated by economic systems at a macro scale to the expenditures of final consumers. However, this top-down approach lacks details at the product level. The level of aggregation of products and services in EEIO tables is generally much larger than the product level considered in





standard process-based Life Cycle Assessment (LCA) approaches. LCA is a bottom-up technique to assess the potential environmental impacts of a product, activity or process throughout its life cycle from raw material acquisition to production, use and waste management stages. From a detail-oriented perspective, LCA methods can offer higher accuracy in estimations at their best. However, estimating the emissions of a whole consumption category or industry by exclusively applying the LCA method would force one to assume a limited number of products/processes to represent a consumption category and, hence, lose accuracy on the general category estimation.

On the other hand, the IO analysis provides a better general category estimation, accounting for a wider range of category characteristics and, eventually, a more desirable overview. Therefore, integrating both ways of emissions accountancy and using each to fit the consumption category best leads to a clearer understanding of the household consumption impact. LCA and EEIO tables cover various impact categories, such as land use, water use, acidification, eutrophication and greenhouse gas emissions. Putting the two methods together provides a clearer understanding of household consumption (Berners-Lee, 2020).

2.3 Global Multiregional Input-Output Databases

Global Multi-Regional Input-Output (GMRIO) have a broader scope than MRIOs and provides a detailed understanding of the global economic system. The global GMRIO models are widely used to analyze the economic interdependencies between regions in the context of global trade and environmental research. GMRIO has proved useful for describing and understanding supply chains and relationships between consuming and producing sectors (Huo et al., 2022). Thus, it is the preferred approach for estimating transactions to carbon. MRIO tables connect the sectors in different regions along the supply chain and track both direct and indirect impacts of global production (Huo et al., 2022; Tukker et al., 2020). Several GMRIO tables are available with different scopes and reach; each GMRIO varies in the country coverage, sectors, and products under analysis (Figure 2).

Several authors have performed an in-depth analysis of the limitations and advantages when applying the different GMRIOs (Dawkins et al., 2019; European Commission. Statistical Office of the European Union., 2021; Huo et al., 2022; Steubing et al., 2022; Tukker et al., 2020), the main findings are presented in Box 1.







Figure 1. Characteristics of existing GMRIOs

Source: (Huo et al., 2022; Mangır & Şahin, 2022; Tukker et al., 2020). For further information on OECD ICIO, see OECD.Stat (2022), GTAP see (Purdue University (2019), EXIOBASE see Stadler et al. (2018), WIOD see Dietzenbacher et al. (2013) and EORA see KGM & Associates Pty. Ltd. (2023).

Box 1. Available GMRIO databases used for consumption-based accounting.

- EXIOBASE focuses on environmental accounts, but mainly for EU countries. It has the highest level of sectoral detail in all countries covered in its database, including 163 sectors in EXIOBASE 3. In EXIOBASE V3.8, the trade and macroeconomic data run up to 2022 based on forecasts. However, EXIOBASE 3 (V3.8) only covers 28 EU member countries plus 16 major economies and five other regions. EXIOBASE 3rx disaggregates to 214 countries, based on EXIOBASE 3.
- Eora is a global, high-resolution GMRIO database covering 187 individual countries with a total sectoral detail of 15,909 sectors, spanning a time series of 21 years. The Eora energy accounts are built on national energy data wherever available. Nevertheless, these cases only represent a small fraction of the countries in the model. Despite its large and detailed database, Eora does have some notable limitations. For instance, its detail on sectors is highly variable (ranging from 26 to over 400 sectors), which limits cross-country comparisons for specific sectors and only provides consistent data for 26 sectors across all countries.
- The OECD inter-country input-output (ICIO) table was first constructed during the joint OECD WTO project on Trade in Value Added (TiVA). Production-based CO₂ emissions by ICIO industries are directly estimated from the IEA CO₂ fuel combustion data. For most CO₂ flows, a straightforward allocation to the ICIO industries is possible. The OECD ICIO has limited sectoral detail, including just 45 aggregated sectors.





Box 1. Available GMRIO databases used for consumption-based accounting (cont.)

- The Global Trade Analysis Project (GTAP) provides a harmonized database with IOTs and trade data that can be used to construct MRIO tables. GTAP covers 121 countries and 20 aggregated regions. The GTAP 10 MRIO consists of /65 sectors (76 sectors in the GTAP-Power database), which makes adequate assessments of specific sectors difficult, especially highly diverse service sectors. Moreover, GTAP provides MRIO tables only at three- or four-year intervals.
- WIOD. The World Input-Output Database (WIOD) is based on raw data from national statistical institutes (NSIs) and UN COMTRADE and covers 1995–2011. The main source for the energy reported in the WIOD database is the energy balances provided by the IEA, except in cases in which equivalent data from NSIs were available. Emissions datasets for EU countries were retrieved from Eurostat.
- IDE-JETRO, Asian Development Bank (ADB) and the Institute of Developing Economies, Japan External Trade Organisation, Tokyo (IDE-JETRO) mainly cover the Asia Pacific region. ADB expands the WIOD database to cover Asian economies. To address any specific informational and analytical needs associated with this region, the ADB MRIO tables cover 25 Asian emerging economies. The IDE-JETRO database also mainly focuses on Asian economies, which limits its usefulness for emerging economies in other world regions.
- FIGARO is a compilation of intercountry SUTs and IOTs at the EU level (European Commission. Statistical Office of the European Union., 2021; Mangır & Şahin, 2022; Steubing et al., 2022; Tukker et al., 2020).





3. Methodology

The following figure outlines our five-step approach for calculating a person's transaction-to-carbon footprint.



Figure 2. A five-step process for estimating carbon intensity factors.

3.1 Analysis of the context

As governments worldwide make more ambitious net-zero commitments, they are increasing attention to household greenhouse gas emissions (Reeve & Aisbett, 2022). Carbon emissions are very specific to the country in which people live. Thus, the first step is to gather contextual information about the country. The national data sources provide a reference to set the base values. Public emissions accounting frameworks - developed for National Accounts - possess attributes of relative simplicity and modularity, which make them worthy of consideration as a starting point for the development of consumption-based accounting. Particularly for developed countries, the regulation requires reporting on air emissions in thousand tons and kilograms per capita.

Environmental accounts are a statistical system bringing together economic and environmental information in a common framework to measure the contribution of the environment to the economy and the impact of the economy on the environment (S. E. Eurostat, 2021). Environmental accounts are a reliable source as they organize environmental data from many domains using the same concepts and terminology as national accounts. Thus, they show the interaction between economic, household, and environmental factors and are more informative than national accounts alone. They are designed to answer questions: Which industry emits the most greenhouse gases? How do patterns of consumption and production affect the





environment? What is the effect of economic policy measures, such as an environmental tax, on the generation of waste or air emissions? How fast is the environmental economy growing, and how does it compare with the rest?

During the context analysis process, information regarding official data related to population, energy matrix, and trade balance, among other elements, is also documented to provide an understandable overview of each country's scenario. To assure consistency through the analysis, the latest population and household size values are employed to make comparisons. The national benchmark value is identified from each country's National Greenhouse Gas Emissions Inventories. This value is used to reference the end-user regarding their overall carbon footprint. Nonetheless, the value is not appropriate for gleaning insights into personal, individual spending for consumption; thus, we need to provide a higher level of granularity regarding carbon footprint per consumption category.

3.2 Carbon intensities for household consumption categories

To provide a carbon intensity factor for different consumption categories, we use a combination of process-based and input-output approaches as applied by Berners-Lee (2020). Referencing the data available for the European Union, where the EXIOBASE is available, we provide 51 categories (Figure 4) to cover the whole household consumption spectrum. The total number of consumption categories is not fixed as it depends on the quality and data availability specific to the country under study.

A. Multiregional Input Output Tables

B. LCA

C. Global values



- 2. Catering
- 3. Convenience stores
- 4. Groceries
- 5. Rent/home
- 6. Drug stores
- 7. Lodging &
- accommodation
- 8. Travel agencies 9. Clothing/shopping
- 10.Furniture
- 11.Personal care
- 12.Other personal effects
- 13.Social protection
- 14.Alcoholic beverages
- 15.Non-alcoholic beverages
- 16.Footwear/shopping
- 17.Water supply
- 18.Maintenance, repair &
- security 19.Household appliances
- 20.Tools and equipment for
- house and gardens 21.Local public
- transportation
- 22.Train travel

- 24. Recreational and cultural services 25.Other recreational items 26.Other major durables for recreation
- 27.Newspaper, books and stationary
- 28.Education

23. Air travel

- 29. Household textiles
- 30.Glassware, tableware and household utensils
- 31. Purchase of vehicles 32.Operation of personal
- transport equipment
- 33. Outpatient care services 34. Other health services
- 35.Insurance
- 36. Financial services 37.Other services
- 38.Communication
- 39.Audio, visual, photographic
- and information equipment 40.Tobacco
- 41.General







Figure 3. Household consumption categories indicate the source of information for the carbon intensity factors.

The complete explanation for each of the 51 categories is available in Appendix 10.1.

3.2.1 Categories derived from the GMRIO

The GMRIO estimates emissions for goods and services by collecting data on the economic value of goods and services purchased and multiplying it by relevant secondary (e.g., industry average) emission factors (e.g., average emissions per monetary value of goods) (Barrow et al., 2013). The EXIOBASE 3 GMRIO environmental accounting provides a high and consistent level of sector detail for the economic activities that create high but diverging environmental pressures, such as agriculture, mining, and energy extraction (Stadler et al., 2018), particularly for Europe, 16 major countries and five regions.

Emission factors are taken from GMRIO Tables (Stadler et al., 2021b), representing cradle-to-gate GHG emissions for a given industry or product category (Barrow et al., 2013). The output of EEIO models is typically the number of GHGs emitted per unit of revenue in a particular industry sector. For instance, EXIOBASE reports specific industry emission factors using the Third Revision of the International Standard Industrial Classification of all Economic Activities (Department of International Economic and Social Affairs, 1990).

Emission factors from EXIOBASE are further allocated to the nomenclature of consumption following the Classification of Individual Consumption According to Purpose (COICOP). COICOP is the international reference classification of household expenditure and an integral part of the System of National Accounts (UN, 2018), which provides a framework for homogeneous categories of goods and services.

For the allocation from EXIOBASE emissions to COICOP, the allocation proposed by Castellani et al. (2019) is used. For allocation at the subcategory level within the COICOP, the allocation tables for European countries from Cai & Vandyck (2020) are used as references.

Based on the GMRIO, we also derived the General category. This value is used when there is no specific information regarding the type of consumption transaction made by the consumer and is classified as general. It gives an average emission intensity for the total emissions and total household consumption expenditures in the country under analysis. It represents the average grams of CO_2e per each monetary unit spent.





3.2.2 Categories derived from LCA ~ functional units.

The process-oriented approach allows a fine estimation of GHG value per functional unit (i.e., passenger-km, kWh, etc.); emissions are then monetized using the market price value of that functional unit. In some cases, the market price is influenced by public subsidies that distort the perception of the real monetary value; there, a readjustment according to the governmental support is needed.

Energy

Energy bills are classified under this category. To estimate the emissions factor for energy, we use the CO₂e emission per unit of electricity produced/consumed specified for the country under analysis. When analyzing the different methodologies for estimating the CO₂e emission factor per unit, we recommend using the consumption data estimated using the integral method. The integral method is based on the total (renewable plus non-renewable) electricity production in proportion to the use of natural gas, coal, and nuclear energy allocated to electricity. Electricity from waste incineration plants and residual gases is not included. Regarding expenditures, we follow market price values, measured by how much the customer pays on the monthly bill; we use the official price per kilowatt-hour (kWh) as specified by the energy companies. To obtain the grams of CO₂e per currency unit for energy, we monetized the carbon intensity factor by dividing the CO₂e by the price per kWh.

Note: it is impossible at the transaction level to identify if the electricity is from fossil fuels or renewable sources; any adjustment to the carbon footprint must be implemented by engaging the user. See section 4.4 for refinements related to renewable energy.

E-Mobility

This category includes electrically driven vehicles, such as e-bikes or pedelecs, electric motorbikes, and electric scooters. For simplicity, emissions associated with this category represent the emissions associated with the carbon intensity for electricity.

Taxi cabs and Limousines

This category covers the transport of individuals and groups of persons and accompanied luggage by share taxis and hire vehicles with driver. These hire vehicles are smaller than buses and usually take passengers on a fixed or semi-fixed route without timetables. They may stop anywhere to pick up or drop off their passengers. The vehicles used as share taxis range from four-seat cars to minibuses. They are often owner-operated. Taxi cabs and limousines' estimate of CO_2e per currency unit depends on the average CO_2e from a standard





passenger car and the market price per kilometre.

Secondhand clothing

This category includes merchandise or secondhand goods such as accessories, shoes, and clothing. The carbon intensity factor is estimated by reducing 42% of the clothing carbon intensity factor to reflect the reduction in emissions associated with the consumption of secondhand cloth¹.

Service Stations

This category includes transactions in service stations and automated fuel dispensers that supply petrol, diesel, and other related products to road vehicles. Emissions are generated from the entire aspect of a fuel's life, i.e. feedstock extraction, refining, transport, and combustion. Expenditure data is based on the market price per litre for a fuel type and is averaged for the last 12 months to account for the dynamic changes in fuel prices. Sales volume of the different fuel types or the share of passenger cars by fuel type is taken as a weighting factor to calculate the average emission intensity in grams of CO_2e per currency unit for the category.

In our estimation, we focus on vehicle refuelling, and it is challenging to identify the type of fuel the consumer is paying for. Adjustments to the carbon footprint based on the fuel refuelled must be implemented by engaging the user. See section 4.4 on refinements for more details.

3.2.3 Categories derived from global data

Although most categories are defined as local categories, meaning local country-specific data is employed to calculate the carbon footprints, a few categories are treated as global, meaning global data is applied for the category. This country-specific approach reflects and considers the prevalent significant variance regarding expenditures and emissions, which particularly apply to certain consumption categories, e.g., 'groceries,' where the locality of consumption considerably affects the carbon footprint. For the global categories, it is assumed that the locality of consumption does not significantly affect the carbon footprint due to cross-border.

¹ The use of second hand clothing has been studied by Farrant et al (2010) and Navodit et al. (2019) considering the Life cycle stages of collecting second-hand apparel, retail & distribution, and use & end-of-life stages. According to the Comparative Life Cycle Assessment (LCA) of SHC vs new clothing conducted by Navodit et al., 2019 using second-hand clothes generates only 16.6 kg CO2e, equal to 58% of the CO2 impact the new clothes create.





Video Streaming Services

The carbon footprint of video streaming mainly comprises the electricity needed to transmit and host the data. The most relevant drivers for carbon emissions in video delivery are data centres, IP core networks, and access networks. Generally, the more data is transmitted, the more energy is required, increasing the carbon footprint. The final footprint is calculated by the average transmission of 1,9 GB/h, the monthly streaming time, and the energy used to transmit the resulting data. Local market prices are used to estimate the final carbon intensity factor.

Audio Streaming Services

The carbon footprint of audio streaming is mainly the amount of electricity needed to transmit and host the data. Generally, the more data transferred, the higher the energy required, which increases the carbon footprint. The hourly transmitted data with 160 kbps and the average monthly listening time calculate the final footprint. Local market prices are used to estimate the final carbon intensity factor. The most relevant drivers for carbon emissions in audio delivery are data centres, IP core networks, and access networks.

Online shopping

Online shopping includes all items purchased online. The footprint of online shopping is estimated using the carbon intensity factor (grams of CO_2e per dollar of gross merchandise sales) based on Amazon's Enterprise-Wide Carbon Footprint report as a major e-commerce market share provider.

Car Rental

This category includes transactions related to vehicle renting services through car rental companies. Carbon emissions account for the whole corporate footprint of a generic car rental provider averaged over major market players' values, including direct activities (administration, transporting the fleet, preparing and cleaning vehicles in-house, etc.), subcontractors' emissions, and customers. Expenditure data is derived from the generic car rental provider's income. Fuel consumption-related emissions from the rental fleet are consciously excluded as they are allocated to the Service Station category as the associated expenditure depends on the customer.





3.3 Carbon footprint refinement: a person is not a category.

Refinements aim to increase the precision of carbon footprint and increase customer satisfaction. Refinements capture individual preferences; thus, successful implementation requires end-user engagement. In the context of the transaction to carbon estimations, refinements require end-user engagement to provide information that will allow to:



Figure 4. Objectives of capturing individual preferences ((IPCC, 2019)

ecolytiq offers two main types of refinements for seven categories (Figure 6), allowing us to provide a more precise estimation and end-user profiling. They are:

- User-based
 - Profile the end customer allowing for extrapolating information about the end user based on known traits or tendencies.
- Transaction-based
 - Adjust transaction-specific calculations based on information provided by the customer for a specific transaction.
 - Recategorization is done by the end-user when changing the type of category of the expenditure.





Figure 5. Refinements (reduction percentages are from Germany and presented here for illustrative purposes)

ecolytiq engages the customer in improving awareness regarding their diet preferences, energy and fuel purchases. The user-based refinements capture preferences that are stable over time. This allows us to measure the impact of the exposure to the information regarding their carbon footprint and identify the resulting changes in individual behaviour. Figure 6 shows the percentual reduction of the carbon footprint for the specific category; this means that depending on the diet preference of the individual, his carbon footprint on groceries can be reduced up to 84% for the case of Germany. The calculation approach is the following:

$\frac{Value \ of \ CO_2e}{transaction} = \frac{base \ value \ CO_2e \ per \ category}{monetary \ unit} * adjustment \ factor$

The adjustment factor is then understood as a numerical factor to obtain the carbon intensity values of the refinement options from the base value. It adjusts the baseline emission intensity to reflect better users' consumption preferences. Figure 7 shows the different answers to the refinement questions. The focus is on refining the categories that contribute the most to GHG emissions from household consumption and are easier to understand for the user. For instance, grocery purchases are among households' topmost consumption categories daily, with a relevant impact on the total expenditure share. An in-depth analysis takes place to identify the options for the category to refine and the corresponding adjustment factors. The carbon footprint associated with groceries can be refined by considering individual diet preferences; the refinement is done by applying adjustment factors derived





from the research led by Kim et al. (2020), which modelled the greenhouse gas and water footprints of nine diets aligned with criteria for a healthy diet specific to 140 countries. This scientific publication estimates footprint reduction when shifting between diets and carbon and water footprints of different food categories per serving, kilocalories, protein content, and edible kilograms. The model considers trade flows when addressing the environmental impact of national consumption patterns. Furthermore, the GHG and water footprints of international food items are attributed to countries where the food is consumed, focusing accountability on the population responsible for changing demand. The diets identified by the study are then provided as options with adjustment factors developed for each country's scenario (Figure 6).



Figure 6. Sources for the adjustment factors of the refinements *and answer options per category* (ICAO, 2018; B. F. Kim et al., 2020; Ricaurte & Jagarajan, 2021)

Another example is the refinement associated with the expenditure from energy usage at home. At the transaction level, and being conservative in the estimations, the default option estimated is based on the energy matrix in the country. This factor then becomes the default value to be affected by the refinement.

Renewable energy (RE) sources such as solar, hydropower, and wind have been some of the most rapidly expanding sources of electricity in recent years. The expansion of renewable energy is one of the central pillars in many countries' energy transition strategy that shifts their dependency away from fossil fuels. Accounting for CO₂e emissions associated with renewable energy is essential to implement demand-side solutions in climate change mitigation efficiently. Energy-related information is a common strategy to promote conservation





behaviour; providing information increases households' awareness of energy consumption, problems, and knowledge about alternatives to reduce consumption. Emissions per energy source are derived from the Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change (IPCC, 2012). The study results allow us to compare conventional power generation systems to renewables because it accounts for GHG emissions across the full life cycle of each technology and therefore help inform decision-makers of the attributable environmental impacts of energy technologies (Dolan & Heath, 2012). Grams of carbon dioxide (CO2) equivalent per kilowatt-hour for each stage of the life cycle for photovoltaics (PV), wind, concentrating solar power (CSP), and hydropower RE systems and coal are identified (Figure 8); most emissions are concentrated during the upstream processes. The wind has the lowest emissions, followed by CSP and PV. For comparison, emissions associated with coal for the different life cycle stages are included.

	Life cycle stages			Life cycle	Medium	
Energy system	Upstream processes ^a	Operational ^b	Downstream Processes ^c	GHG emission gCO2eq/kWh	LCOE ^d (in ^{USS)} (IEA & NEA, 2020; IRENA, 2021)	
Photovoltaics (PV) (Hsu et al., 2012; H. C. Kim et al., 2012; NREL, 2012)	~60-70%	~21-26%	~5-20%	~43 g CO2eq/kWh	0.056/kWh	
Wind (average for Land- based and offshore wind technologies) (Dolan & Heath, 2012; IPCC, 2012; NREL, 2012)	~ 86%	~9%	~5%	~13 g CO2eq/kWh	0.050/kWh (onshore) 0.088/kWh (offshore)	
Concentrating Solar Power (Burkhardt III et al., 2012; If 2012)	-70%	~21-26%	~5-20%	~28 g CO2 eq/kWh	0.121/kWh	
Hydropower	7 ~13-39% 7	~30-60%	~4-20%	~ 21 g CO2 eq/kWh	0.068/kWh (run of river>=5MW) 0.088/kWh (reservoir >=5MW)	
Coal (Whitaker et al., 2012)	< 1%	>98%	<1%	~1,001 g CO2eq/kWh	0.088/kWh	

^a considers raw materials, extraction, module manufacture, parts manufacture, system/plant/farm construction

^b considers power general, plant operation, and maintenance. For coal, it includes coal mining/coal preparation, coal transport, and coal combustion

^c considers system/plant/farm decommissioning. For coal, it includes power plant decommissioning, waste disposal, coal mine land rehabilitation

^d LCOE stands for levelised costs of generating electricity

Figure 7. Comparison of Life cycle GHG emission for photovoltaics, wind, concentrating solar power,





hydropower, and coal systems

The market price per kWh of renewable energy is used to estimate carbon intensity. The energy costs are those a customer pays the energy supplier for the electricity consumed and differ depending on the energy supplier, the network costs, and the taxes prescribed by the federal, state, and local governments.

Prices vary widely, and energy providers are recalculating their tariffs regularly. Thus, country-specific revision should be performed to compare prices for each type of renewable energy system (i.e., identifying min and max values and regional differences) to make a solid approximation of the market price per kWh. To provide an example, a market price review for wind and solar Energy in Germany was performed based on the comparison portal from the Environmental Association (Vergleichsportal der Umweltverbände) and the green electricity comparison (Ökostromvergleich) from check24. The market price review showed that the unit price does not change depending on the number of people per household; however, consumption varies, so the consumer pays accordingly. It was impossible to disentangle price differentiation between PV and CSP; therefore, the price shown considers both systems.

The reference value for consumption is:

- One person: 1,500 kWh per year
- Two people: 2,400 kWh per year
- Three people: 3,200 kWh per year
- Four people: 3,800 kWh per year

Prices change if consumption exceeds 10,000 kWh or 50,000 kWh annually; it varies per electricity provider.

En	Euro/kWh	
Solar	Photovoltaics (PV) & CSP	0.78 (0.62-1.08 euro)*
Wind (average for 2012;	Land-based and offshore wind technologies) (Dolan & Heath, IPCC, 2012; NREL, 2012)	0.75 (0.631-1.72 euro)*
2021)	Hydropower(Robin Wood,	0.5 (0.5-1.5 euro)*
Regular (Coal,	mix natural gas)	0.475

Figure 8. Comparison of market prices among solar, wind, hydropower, and the regular mix of electricity in Germany





*Price range, minimum and maximum market price per kWh in Germany

Using market price and emissions from RE systems, carbon intensity (CI) is calculated.

$$CI_{RE} = \frac{emission \text{ per RE system } gCO_2eq/kWh}{price/kWh}$$

See Appendix 10.3 for the full report on energy refinement.

Like diet and energy, a full report is developed with the research supporting the different options. The refinements are country specific. The full list of questions and answers is available in Appendix 10.2.

3.4 Update of the estimations

Estimations should be reviewed and updated yearly. Depending on the data source, some estimations will require revision in six months. The developing team decides this, and a date for the following revision is agreed upon.





4. Limitations

- Due to data collection difficulties and data compilation constraints, many existing MRIO databases (Tukker & Dietzenbacher, 2013) do not release annual MRIO tables. This impedes the ability to analyze historical supply chain data and international trade patterns to forecast future trends.(Huo et al., 2022; Huysman et al., 2016).
- 2. The resolution of MRIO assessments is limited to a number of sectors. Anything more detailed requires additional data and deeper analysis. The National Footprint and Biocapacity Accounts have continuous time series from 1961 onwards, while GTAP data are limited to four years (2004, 2007, 2011, 2014).
- 3. MRIOs have different scopes in industries and products; thus, values are not always comparable. For instance, EXIOBASE 3 provides:
 - A product-by-product table based on the industry technology assumption.
 - An industry-by-industry table based on the fixed product sales assumption.

The industry technology assumption assumes that each industry has its specific technology (in terms of inputs), irrespective of the product mix of that industry. Fixed product sales structure assumption that each product has its own specific sales structure, irrespective of the industry where it is produced (E.: S. A. der E. G. Eurostat, 2008)

- 4. Constant prices for categories are estimated using the functional units when monetized. Average prices for the last 12 months are used; thus, price differences over time are not considered.
- 5. Data inconsistencies across time and countries, ranging from changes in classifications to modifications of the underlying accounting concepts over time. Understandably, the statistical agencies improve their approaches over time. Still, if the statistical agencies do not revise the older time series according to the new concepts, the time series are not directly usable for analysing structural changes over time (Stadler et al., 2021a).
- 6. Uncertainty and assumptions regarding modelling performed by third-party data researchers are out of ecolytiq's control.
 - 7. Language barriers when dealing with non-European national statistical agencies 'data. Data available in the original language and English differ, so local knowledge becomes essential for appropriate data usage.
 - 8. Dependency on public information, update of the emissions factor is plane annually, nonetheless, its application is subject to modelling and data availability from third parties.





5.Concluding remarks

This methodology approximates the real value; it is not an accurate factor that mimics the complex reality of our day-to-day activities. However, it provides a reference value to incentivize changes in consumption patterns.

Companies offering carbon intensities factors should specify which GMRIO is being used to compare values and strengthen consumer trust on the overall strategy.

As much as knowledge about the impact of global warming is valuable, it is only the first step in a long process of individual change in behaviour toward sustainable lifestyles.





6. Further reading

The purpose of this methodology is to propose a solid approach to building transaction-to-carbon emission factors. We recommend to further reading the following:

- An open standard framework for consumer carbon calculations based on payment transactions.
- Country profiles specifying reference values for emission and consumption, benchmark values, and sources of information are available on the OSR website.

The methodology has been applied to estimate carbon intensity factors for the following countries: Germany, Sweden, The Netherlands, Norway, France, and Ireland.

Participation by the whole community in innovating and improving this methodology and the Open Standard framework leads naturally to one of the big outstanding questions: what other aspects of TtC systems should be 'open,' that is, freely accessible to the community. Your data, algorithms, and program code have value. However, the proprietary value may be exceeded by the value created If some of these are open source. Open-source projects can be more secure, accurate, and comprehensive while communicating to certain actors - hackers and consumers about your intentions and ethics. Open source does not necessarily mean your endproduct is free, which would be 'Free and Open-Source software (FOSS)", though some innovators may wish to move in this direction and earn their profits through services.





7.Glossary

Carbon footprint	A measure of the exclusive total amount of carbon dioxide (CO ₂) emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product.			
Carbon intensity	The amount of emissions of carbon dioxide (CO2) and/or equivalent carbon dioxide (CO2e) released per unit of another variable such as gross domestic product (GDP), output energy use, or transport.			
COICOP	The Classification of Individual Consumption According to Purpose (COICOP) is the international reference classification of household expenditure. COICOP aims to provide a framework of homogeneous categories of goods and services, which are considered a function or purpose of household consumption expenditure.			
Country profiles	Is the report per the reporting guidelines of the Open Standard framework for consumer carbon calculations based on payment transactions.			
Emissions	The release of Greenhouse gases (GHGs) into the atmosphere.			
EEIO-hybrid	Environmentally extended input-output (EEIO) hybrid methodology estimates carbon intensity factors from EEIO tables and life-cycle assessment data			
EXIOBASE	EXIOBASE is a global, detailed Multiregional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT). It was developed by harmonizing and detailing supply-use tables for many countries, estimating emissions and resource extractions by industry. Subsequently, the country supply-use tables were linked via trade, creating an MR- SUT and producing MR-IOTs. The MR-IOT can be used to analyze the environmental impacts associated with the			



final consumption of product groups.

- EXIOBASE3 EXIOBASE3 is one of the most extensive Environmentally Extended Multiregional Input-Output (EE-MRIO) systems available worldwide. EXIOBASE 3 builds upon the previous versions of EXIOBASE by using rectangular supply-use tables (SUT) in 163 industries, with 200 products classified as the main building blocks. The data comes in two versions: a monetary version consistent with macroeconomic accounts and a hybrid mixed-unit version.
- Emission factor A factor allowing GHG emissions to be estimated from a unit of available activity data.
- Greenhouse Greenhouse gases are those gaseous constituents of the gases (GHGs) atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3) are the primary GHGs in the Earth's atmosphere. This property causes the greenhouse effect.
- GlobalIt is a factor describing the radiative forcing impactwarming(degree of harm to the atmosphere) of one unit of a givenpotentialGHG relative to one unit of CO2 over a given period.(GWP)(GWP)
- NACE NACE is a four-digit classification providing the framework for collecting and presenting a large range of statistical data according to economic activity in economic statistics (e.g., production, employment, and national accounts) and other statistical domains developed within the European statistical system (ESS).
- TtC Consumers' carbon estimations based on payment transactions.
- The System of is а framework that integrates economic Environmentaland environmental data provide to а more Economic comprehensive and multipurpose view of the Accounting interrelationships between the economy and the



(SEEA)

environment and the stocks and changes in stocks of environmental assets as they benefit humanity. It contains the internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics and accounts. The SEEA framework follows a similar accounting structure as the System of National Accounts (SNA). The framework uses concepts, definitions and classifications consistent with the SNA to facilitate the integration of environmental and economic statistics. The SEEA is a multi-purpose system that generates various statistics, accounts and indicators with many potential analytical applications. It is a flexible system that can be adapted to countries' priorities and policy needs while providing a common framework, concepts, terms and definitions.



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9.Appendix

9.1 Appendix 1. Explanation for all categories

The EEIO-hybrid is a top-down approach called the Environmentally Extended Input-Output approach or EEIO. The approach mainly relies on the household consumption model based on expenditures. Depending on the client's needs and the taxonomy of the transactions, the categories can be organized into different meta-categories. Here you will find the description of the transactions that are accounted for in each category. Thus, these explanations reflect and use the language of the international accounting system for household consumption.

Note: these are standard technical explanations available to our clients for matching and understanding purposes. The description must be tailored based on the country and should be shorted/reviewed for front-end display.

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Social protection	
Taxi Cabs and Limousines	
Tobacco	
Tools and Equipment for House and Garden	
Train Travel	
Travel- Package Holidays	
Video Streaming Services	
Water Supply and Miscellaneous Services	

Air Travel

Transport individuals and groups of persons and luggage by airplane. Flights are defined as air travel. Influencing factors are the industry's total emissions and the industry's revenue. By dividing the flight industry's total emissions by its revenues, we calculate grams of CO_2e per Euro.

Alcoholic Beverages

Includes spirits, wine, and beer. The group excludes: Alcoholic beverages are sold for immediate consumption away from home by hotels, restaurants, cafes, bars, kiosks, street vendors, automatic vending machines, etc. The national accounting system (Eurostat) reports on emissions and expenditures for alcoholic beverages. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.



Audio Streaming Services

The carbon footprint of audio streaming is mainly the amount of electricity needed to transmit data. Generally, the more data transferred, the higher the energy required, which increases the carbon footprint. The hourly transmitted data with 160 kbps and the average monthly listening time calculate the final footprint. Local market prices are used to estimate the final carbon intensity factor. The most relevant drivers for carbon emissions in audio delivery are data centres, IP core networks, and access networks.

Audio-Visual, Photographic, and Information-Processing Equipment:

The national accounting system (Eurostat) reports on emissions and expenditures for audio-visual, photographic, and information-processing equipment. Includes reception, recording, and reproduction of sound and pictures, photographic and cinematographic equipment and optical instruments, information processing equipment, recording media, and repair of audio-visual, photographic, and information processing equipment. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Bakeries and Cafes / Catering:

This group covers food and beverage serving services provided by restaurants, cafés, and similar facilities, either with full, limited, or self-service, or by canteens, cafeterias, or refectories at work or school and other educational establishment's premises. The group includes Restaurants, cafes and canteens, university refectories, military messes, and wardrooms. The group excludes Tobacco purchases, telephone calls, and food and drink provided to hospital in-patients. The national accounting system (Eurostat) reports on emissions and expenditures for Bakeries & Cafés & Catering services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Car Rental

Includes transactions related to vehicle renting services through car rental companies. Carbon emissions account for the whole corporate footprint of a generic car rental provider averaged over major market players' values, including direct activities (administration, transporting the fleet, preparing and cleaning vehicles inhouse, etc.), subcontractors' emissions, and customers. Fuel consumption-related emissions from the rental fleet are consciously excluded as they are allocated to the Service Station category as the associated expenditure depends on the customer. Expenditure data is derived from the generic car rental provider's income.



Clothes/Shopping

Includes clothing materials, garments, other clothing and accessories articles, cleaning, repair, and clothing hire. The group excludes Furnishing fabrics, Articles of medical hosiery such as elasticated stockings, babies' napkins, gloves and other articles made of rubber, pins, safety pins, sewing needles, knitting needles, thimbles, protective headgear for sports, other protective gear for sports such as life jackets, boxing gloves, belts, supports, etc. paper handkerchiefs, watches, jewellery, cuff links, tiepins, walking sticks and canes, umbrellas and parasols, fans, keyrings. The national accounting system (Eurostat) reports on emissions and expenditures for clothing, including all transactions related to garments, other articles of clothing, clothing accessories, cleaning, repair, and hire of clothing. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.

Communication

This category comprises Postal Services, Telephone and Telefax Equipment, and Telephone and Telefax Services. Postal Services is the group that includes payments for the delivery of letters, postcards, and parcels, private mail and parcel delivery, and all purchases of new postage stamps, pre-franked postcards, and aerogrammes. The group excludes purchases of used or cancelled postage stamps and financial services of post offices. Telephone and Telefax Equipment is the group that includes purchases of telephones, radio-telephones, telefax machines, telephone-answering machines, telephone loudspeakers, and repair of such equipment. The group excludes telefax and telephone-answering facilities provided by personal computers. Telephone and Telefax Services is the group includes installation and subscription costs of personal telephone equipment, telephone calls from a private line or a public line (public telephone box, post office cabin, etc.), telephone calls from hotels, cafes, restaurants, and the like, telegraphy, telex and telefax services, information transmission services; Internet connection services, hire of telephones, telefax machines, telephone answering machines, and telephone loudspeakers. The national accounting system (OECD.Stat) reports on emissions and expenditures for all three categories included in this category. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.

Convenience Stores

Includes goods and services for routine household maintenance, particularly those transactions related to non-durable household goods and domestic and household services. The group excludes brushes and scrapers for paint, varnish, and wallpaper; fire extinguishers for transport equipment; Products specifically for the cleaning and maintenance of transport equipment such as paints, chrome, cleaners, sealing compounds, and bodywork polishes; horticultural products for the upkeep of ornamental gardens, Paper handkerchiefs, toilet paper, toilet soaps, toilet sponges and other products for personal hygiene cigarette, cigar and pipe lighters and lighter



fuel, Dry-cleaning, laundering and dyeing of garments, Refuse collection, Sewerage collection, Co-proprietor charges for caretaking, gardening, stairwell cleaning, heating and lighting, maintenance of lifts and refuse disposal chutes, etc. in multi-occupied buildings, Security services, Snow removal, and chimney sweeping, Removal and storage services, Services of wet nurses, creches, daycare centres, and other child-minding facilities, Bodyguards. The national accounting system (Eurostat) reports on emissions and expenditures for convenience stores. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Drug Stores - Medical Products, Appliances, and Equipment:

This group covers medicaments, prostheses, medical appliances and equipment, and other health-related products purchased by individuals or households, either with or without a prescription, usually from dispensing chemists, pharmacists, or medical equipment suppliers. The group includes pharmaceutical products, medical products, therapeutic appliances, and equipment. The group excludes veterinary products, therapeutic equipment, protective goggles, belts and supports for sport, and sunglasses not fitted with corrective lenses. The national accounting system (Eurostat) reports on emissions and expenditures for drug stores. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

E-Mobility

This category includes electrically driven vehicles, such as e-bikes or pedelecs, electric motorbikes, and electric scooters. Emissions associated with this category represent the emissions associated with electricity.

Education

The group includes educational programs for adults and children on different levels. The group excludes driving lessons and recreational training courses such as sports or bridge lessons from independent teachers. The national accounting system (Eurostat) reports on emissions and expenditures for education. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Electric Vehicles

This category represents private cars that obtain energy from the power grid. Emissions associated with this category represent the emissions associated with electricity.



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Energy bills are classified under this category. To estimate the emissions factor for energy, we use the CO_2e emission per unit of electricity produced/consumed specified for the country under analysis. When analyzing the different methodologies for estimating the CO_2e emission factor per unit, we recommend using the consumption data estimated using the integral method. The integral method is based on the total (renewable plus non-renewable) electricity production in proportion to the use of natural gas, coal, and nuclear energy allocated to electricity. Electricity from waste incineration plants and residual gases is not included. Regarding expenditures, we follow market price values, measured by how much the customer pays on the monthly bill; we use the official price per kilowatt-hour (kWh) as specified by the energy companies. To obtain the grams of CO_2e per currency unit for energy, we monetized the carbon intensity factor by dividing the CO_2 by the price per kWh.

Financial Services

The group includes financial intermediation services indirectly measured, actual charges for the financial services of banks, post offices, saving banks, money changers, and similar financial institutions, fees and service charges of brokers, investment counsellors, tax consultants, and the like, administrative charges of private pension funds and the like. The national accounting system (Eurostat) reports on emissions and expenditures for financial services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Footwear/shopping

This group covers all general footwear, split by footwear for men, women, infants, and children, and footwear-related services. The group includes shoes and other footwear and repair and hire of footwear. The group excludes babies' booties made of fabric, shoe trees, shoehorns and polishes, creams, and other shoe-cleaning articles, orthopaedic footwear, game-specific footwear, shin guards, cricket pads, and other such protective apparel for sport, parts of footwear, such as heels, soles, etc., Polishes, creams, and other shoe cleaning articles, repair or hire game-specific footwear. The national accounting system (Eurostat) reports on emissions and expenditures for footwear. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Furniture

The group includes furniture and furnishings, carpets and other floor coverings, and repair of furniture, furnishings, and floor coverings. The group excludes bedding and sunshades safes, ornamental glass and ceramic articles, clocks, wall thermometers



and barometers, carrycots and pushchairs, works of art, antique floor coverings, and furniture acquired primarily as stores of value, bathroom mats, rush mats, and doormats., separate purchases of materials made by households to undertake the repair themselves, dry-cleaning of carpets. The national accounting system (Eurostat) reports on emissions and expenditures for furniture. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.

General

This category gives an average emission intensity for the total emissions and household consumption expenditures in the country under analysis. It represents the average grams of CO_2e per each monetary unit spent.

Glassware, Tableware, and Household Utensils:

This category includes glassware, tableware, and household utensils. The group excludes Lighting equipment, electric household appliances, cardboard tableware, personal weighing machines, baby scales and ashtrays. The national accounting system (Eurostat) reports on emissions and expenditures for glassware, tableware, and household utensils. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Groceries

Food: the food products classified here are those purchased for consumption at home. The group includes Bread and cereals, meat, fish and seafood, milk, cheese and eggs, oils and fats, fruit, vegetables, sugar, jam, honey, chocolate and confectionery, and food products not elsewhere classified. The group excludes food products sold for immediate consumption away from home by hotels, restaurants, cafes, bars, kiosks, street vendors, automatic vending machines, etc., cooked dishes prepared by restaurants for consumption off their premises; cooked dishes prepared by catering contractors, whether collected by the customer or delivered to the customer's home Products sold specifically as pet foods. The national accounting system (Eurostat) reports on emissions and expenditures for food products. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.

Household Appliances

The group includes major household appliances, whether electric or not, small electric household appliances, and repair of household appliances. The group excludes appliances that are built into the structure of the building, small non-electric



household articles and kitchen utensils, household scales, personal weighing machines and baby scales, and separate purchases of materials made by households to undertake the repair themselves. The national accounting system (Eurostat) reports on emissions and expenditures for household appliances. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Household Textiles

The group includes household textiles. The group excludes fabric wall coverings, tapestries, floor coverings such as carpets and fitted carpets, electric blankets, covers for motor cars, motorcycles, etc., air mattresses, and sleeping bags. The national accounting system (Eurostat) reports on emissions and expenditures for household textiles. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Insurance

Service charges for insurance are classified by type of insurance, namely: life insurance and non-life insurance (that is, insurance in connection with the dwelling, health, transport, etc.). Service charges for multi-risk insurance covering several risks should be classified based on the cost of the principal risk if it is impossible to allocate the service charges to the various risks covered. Service charge is the difference between claims due and premiums earned and premium supplement. The group includes life insurance, insurance connected with the dwelling, health, transport, and other insurance. The group excludes service charges paid by owner-occupiers for the insurance typically taken out by landlords. The national accounting system (Eurostat) reports on emissions and expenditures for insurance. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Local Public Transport

Transport individuals and groups of persons and luggage by two or more modes of transport when the expenditure cannot be apportioned between them. Includes buses, subways, trams, and commuter trains. Please note that long-distance trains are considered under train travel.

Lodging and Accommodation

Accommodation services include services for visitors and travellers away from their principal or secondary residence. If not separately invoiced, it includes food and beverage services and other services, such as housekeeping, parking, laundry, swimming pools, exercise rooms, recreational facilities, and conference and convention facilities. The national accounting system (Eurostat) reports on emissions and expenditures for lodging and accommodation. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Maintenance Repair and Security



Two features distinguish the maintenance and repair of dwellings: first, they must be undertaken regularly to maintain the dwelling in good working order; second, they do not change the dwelling's performance, capacity, or expected service life. This group includes materials for the maintenance and repair of the dwelling and services for the maintenance and repair of the dwelling. This group excludes fitted carpets and linoleum, hand tools, door fittings, power sockets, wiring flex, and lamp bulbs. Brooms, scrubbing brushes, dusting brushes, and cleaning products. Products, materials, and fixtures used for major maintenance and repair or extension and conversion of the dwelling. Separate purchases of materials made by households to undertake the maintenance or repair themselves, services engaged for major maintenance and repair (intermediate consumption), or extension and conversion of the dwelling (capital formation). The national accounting system (Eurostat) reports on emissions and expenditures for maintenance and repair of the dwelling. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Newspapers, Books, and Stationery:

The group includes books, newspapers, periodicals, miscellaneous printed matter, stationery, and drawing materials. The group excludes Pre-franked postcards and aerogrammes. The national accounting system (Eurostat) reports on emissions and expenditures for newspapers, books, and stationery. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Non-Alcoholic Beverages

The non-alcoholic beverages classified here are purchased for home consumption. The group includes coffee, tea, cocoa, mineral waters, soft drinks, and fruit and vegetable juices. The group excludes non-alcoholic beverages sold for immediate consumption away from home by hotels, restaurants, cafes, bars, kiosks, street vendors, automatic vending machines, etc. The national accounting system (Eurostat) reports on emissions and expenditures for non-alcoholic beverages. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Online shopping

Online shopping includes all items purchased online. The footprint of online shopping is estimated using the carbon intensity factor (grams of CO2e per dollar of gross merchandise sales) based on Amazon's Enterprise-Wide Carbon Footprint report as a major e-commerce market share provider.

Operation of Personal Transport Equipment

Purchases of spare parts, accessories, or lubricants made by households to undertake the maintenance, repair, or intervention themselves should be shown under. The group includes Spare parts and accessories for personal transport equipment, fuels, lubricants for personal transport equipment, and maintenance and repair. The group



excludes crash helmets for motorcycles and bicycles, non-specific products for cleaning and maintenance such as distilled water, household sponges, chamois leathers, detergents, etc., and charges for fitting spare parts and accessories, and the painting, washing, and polishing of bodywork, and radio-telephones, car radios, baby seats for cars. The national accounting system (Eurostat) reports on emissions and expenditures for the operation of personal transport equipment. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Other Health Services

The group includes services of general and specialist hospitals, the services of medical centres, maternity centres, nursing homes, and convalescent homes, which chiefly provide in-patient health care, institutions serving old people in which medical monitoring is an essential component, and the services of rehabilitation centres, in-patient health care and rehabilitative therapy where the objective is to treat the patient rather than to provide long-term support. The group excludes services of facilities, such as surgeries, clinics, and dispensaries, devoted exclusively to outpatient care. Nor does it include the services of retirement homes for elderly persons, institutions for disabled persons, and rehabilitation centres providing primarily long-term support. The national accounting system (Eurostat) reports on emissions and expenditures for other health services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Other Major Durables for Recreation and Culture

The group includes major durables for outdoor recreation, musical instruments, major durables for indoor recreation, and maintenance and repair of other major durables for recreation and culture. The group excludes horses and ponies, horse- or pony-drawn vehicles and related equipment purchased for personal transport, and fuel for recreational vehicles. The national accounting system (Eurostat) reports on emissions and expenditures for other major durables for recreation and culture. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Other Personal Effects

This category includes transactions of jewellery, clocks, watches, other personal effects, other appliances, articles, and products for personal care, and articles for babies/ This category excludes ornaments, radio clocks, precious stones and metals; jewellery fashioned out of such stones and metals acquired primarily as stores of value (capital formation), baby furniture, shopping bags, feeding bottles. The national accounting system (Eurostat) reports on emissions and expenditures for other personal effects. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.



Other Recreational Items and Equipment, Gardens, and Pets

The group includes games, toys and hobbies, equipment for sports, camping, openair recreation, gardens, plants and flowers, pets and related products, and veterinary and other pet services. The group excludes collectors' items in the category of works of art or antiques, unused postage stamps, horses and ponies, gardening gloves, gardening services, gardening equipment, gardening tools, insecticides, and pesticides for household use. The national accounting system (Eurostat) reports on emissions and expenditures for other recreational items and equipment, gardens, and pets. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Other Services

The group includes fees for legal services, employment agencies, etc.; charges for undertaking and other funeral services; payment for the services of estate agents, housing agents, auctioneers, salesroom operators, and other intermediaries; payment for photocopies and other reproductions of documents, fees for the issue of birth, marriage and death certificates and other administrative documents, payment for newspaper notices and advertisements, payment for the services of graphologists, astrologers, private detectives, bodyguards, matrimonial agencies and marriage guidance counsellors, public writers, miscellaneous concessions (seats, toilets, cloakrooms), etc. The national accounting system (Eurostat) reports on emissions and expenditures for other services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Outpatient Care Services

This group covers medical, dental, and paramedical services delivered to outpatients by medical, dental, and paramedical practitioners and auxiliaries. The services may be delivered at home, in individual or group consulting facilities, dispensaries, or the outpatient clinics of hospitals. The group includes Medical services, dental services, and paramedical services. The group excludes Services of medical analysis laboratories and x-ray centres, services of traditional medicine practitioners, dentures, orthodontic specialists, and medical analysis laboratories and x-ray centres. The national accounting system (Eurostat) reports on emissions and expenditures for outpatient care services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO₂e per Euro.

Personal Care



This category includes transactions associated with hairdressing salons and personal grooming establishments, electric appliances for personal care, other appliances, articles, and products for personal care. This category excludes consumption linked to spas, fitness centres, and handkerchiefs made of fabric. The national accounting system (Eurostat) reports on emissions and expenditures for personal care. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Purchase of Vehicles

The purchase of vehicles covers motor cars, motorcycles, bicycles, and animal-drawn vehicles. This category includes motor cars, motorcycles, bicycles, and animal-drawn vehicles; the group excludes invalid carriages, camper vans, golf carts, toy bicycles, tricycles, horses and ponies, horse- or pony-drawn vehicles, and related equipment purchased for recreational purposes. The national accounting system (Eurostat) reports on emissions and expenditures for the purchase of vehicles. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Recreational and Cultural services

The group includes recreational and sporting services, cultural services, and games of chance. The group excludes cable-car car and chairlift transport, not at ski resorts or holiday centres. The national accounting system (Eurostat) reports on emissions and expenditures for recreational and cultural services. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Rent/home

Rentals normally include payment for the use of the land on which the property stands, the dwelling occupied, the fixtures and fittings for heating, plumbing, lighting, etc., and, in the case of a furnished dwelling, the furniture. This group includes Actual rentals paid by tenants, Other actual rentals. This group excludes accommodation services for educational establishments and hostels, retirement homes for the elderly, and accommodation services for holiday villages and centres. The national accounting system (Eurostat) reports on emissions and expenditures for rentals. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Secondhand clothing

Includes merchandise or secondhand goods such as accessories, shoes, and clothing.

Service Stations

This category includes transactions in service stations and automated fuel dispensers that supply petrol, diesel, and other related products to road vehicles. Emissions are generated from the entire aspect of a fuel's life, i.e. feedstock extraction, refining, transport, and combustion. Expenditure data is based on the market price per litre for



a fuel type and is averaged for the last 12 months to account for the dynamic changes in fuel prices. Sales volume of the different fuel types or the share of passenger cars by fuel type is taken as a weighting factor to calculate the average emission intensity in grams of CO_2e per currency unit for the category.

Social protection

Social protection covers assistance and support services provided to persons who are: elderly, disabled, have occupational injuries and diseases, survivors, unemployed, destitute, homeless, low-income earners, indigenous people, immigrants, refugees, alcohol and substance abusers, etc. This group includes residential care, home help, daycare, and rehabilitation. It also covers assistance and support services provided to families and children. More specifically, this class covers payments by households. The national accounting system (Eurostat) reports on emissions and expenditures for social protection. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Taxi Cabs and Limousines

Transport of individuals and groups of persons and accompanied luggage by share taxi and hire vehicle with driver. These hire vehicles are smaller than buses and usually take passengers on a fixed or semi-fixed route without timetables. They may stop anywhere to pick up or drop off their passengers. The vehicles used as share taxis range from four-seat cars to minibuses. They are often owner-operated. Taxi cabs and limousines' estimate of CO_2e per Euro depends on the average CO_2e from standard passenger cars and the market price per kilometre.

Тоbассо

This group covers all purchases of tobacco by households, including purchases of tobacco in restaurants, cafes, bars, and service stations. Tobacco products refer to cigarettes; cigarette tobacco and papers, cigars, pipe tobacco, chewing tobacco, or snuff. The national accounting system (OECD.Stat) reports on emissions and expenditures for tobacco. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Tools and Equipment for House and Garden

This category includes major tools and equipment, small tools, and miscellaneous accessories. The national accounting system (Eurostat) reports on emissions and expenditures for tools and equipment for the house and garden. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Train Travel

The emissions of a train ride depend on the average grams of CO_2e per kilometre per capita and the average distance in kilometres covered per Euro. The spending per km



is calculated with the total person travelled per kilometer and the total revenue generated in trains from the train service companies (e.g., Deutsche Bahn in Germany). The emission intensity of long-distance travel (short-distance travel is included in Local Public Transportation) is as g CO2e/km.

Travel- Package Holidays

The group includes all-inclusive holidays or tours providing travel, food, accommodation, guides, half-day, one-day excursion tours, and pilgrimages. The national accounting system (Eurostat) reports on emissions and expenditures for travel package holidays. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.

Video Streaming Services

The carbon footprint of video streaming mainly comprises the electricity needed to transmit data. The most relevant drivers for carbon emissions in video delivery are data centres, IP core networks, and access networks. Generally, the more data is transmitted, the more energy is required, increasing the carbon footprint. The final footprint is calculated by the average transmission of 1,9 GB/h, the monthly streaming time, and the energy used to transmit the resulting data. Local market prices are used to estimate the final carbon intensity factor.

Water Supply and Miscellaneous Services

The group includes water supply, refuse collection, sewage collection, and other services relating to the dwelling not included elsewhere classified. The group excludes drinking water sold in bottles or containers, hot water or steam purchased from district heating plants, household services such as window cleaning, disinfecting fumigation, pest extermination, and bodyguards. The national accounting system (Eurostat) reports on emissions and expenditures for water supply and miscellaneous services relating to the dwelling. Therefore, by dividing total emissions by expenditure, we calculate grams of CO_2e per Euro.



9.2 Appendix 2. Refinement questions

Note: the description is tailored based on the country and should be shorted/reviewed for front-end display. Adjustment factors do not change.

9.2.1 Profile questions

Diet preferences

Question	Answer	Explanation
What type of dietary option do you identify with?	Meatless day	Please select this option if you have a meatless day; you eat meat only six days a week. (It is assumed a lacto-ovo vegetarian diet for one day per week).
	Meat-based	Please select this option if you eat meat (bovine, sheep, goat, and pig meat) every day of the week.
	Low red meat	Please select this option if you eat a maximum of three servings per week of red meat (i.e., bovine, sheep, goat, pig).
	No red meat	Please select this option if you substitute red meat with poultry and other meat sources.
	No dairy	Please select this option if you have excluded all milk-related products from your diet.
	Low-food chain	Please select this option if you have replaced your source of protein from meat with options like plant-based's forage fish, bivalve molluscs', or insect protein.
	Pescetarian	Please select this option if you have incorporated seafood and fish into an otherwise vegetarian diet.



Question	Answer	Explanation
	(Lacto-ovo) Vegetarian	Please select this option if you have excluded terrestrial and aquatic meats from your diet. (It is assumed six or seven servings per day of fruit and vegetables.)
	2/3 vegan	Please select this option if you have a vegan diet for two of three daily meals. (It is assumed six or seven servings per day of fruit and vegetables.)
	Vegan	Please select this option if your diet is based on plants (such as vegetables, grains, nuts, and fruits) and foods made from plants and excludes food that come from animals, including dairy products and eggs.

Energy

Questions	Answe	rs Explanations
Does your associated cost of housing already include energy costs?	YesNo	
What type of energy do you use at home?	Regular energy matrix	The regular energy matrix refers to electricity generated from fossil fuels (e.g., lignite or coal-fired plants).
	Renewable energy matrix	The renewable energy matrix refers to electricity generated using two or more renewable resources. Please select this option if your electricity provider uses different sources such as hydropower, solar and/or wind to fulfil the household energy requirements.
	Wind energy	Wind energy makes use of the kinetic energy of moving air. It refers to the electricity produced by large wind turbines located on land (onshore) or in the sea- or freshwater (offshore).



Questions	Answe	rs Explanations
	Solar energy	Solar energy uses solar irradiance to produce electricity using photovoltaics (PV) and concentrating solar power (CSP) to produce thermal energy to meet direct lighting needs and potentially produce fuels that might be used for transport and other purposes.
	Hydropower	Hydropower uses the energy of water moving from higher to lower elevations primarily to generate electricity. Hydropower projects encompass dam projects with reservoirs, run-of-river and in-stream projects and cover a continuum in project scale.
	l do not know, but l want to find out	I am unsure what energy I use at home, but I want to find out.

Transportation – Fuel use at service stations

Questions	Answers
Do you own a car?	YesNo
What type of car do you own?	 Mixed / I don't know I do not own a car Gasoline / hybrid gasoline Diesel / hybrid diesel Electric LPG

9.2.2 Transaction-based

Category		Questions		Answers	
Service Stations		Did you buy anyth the service station	iing else at ?	 Convenience stores Only fuel Convenience store and fuel 	
Lodging Accommodation	&	How long is your st What is accommodation's	ay in days? the star	Number of day 1 Star 2 star	/S



Category	Questions	Answers		
	rating?	3 star 4 star 5 star		
Air Travel	How long is your flight? (hours)	From 1 until 19 hours		
	Which class do you travel in?	EconomyBusiness		
	What type of flight is this?	one-wayround-trip		
Taxi	Did you order an electric taxi	YesNo		
Clothing	Did you buy in a secondhand store?	YesNo		





9.3 Appendix 3. Energy refinement -Supplemental fact sheet

Transaction to carbon footprint

Supplemental fact sheet: emissions from renewable energy systems

for conscious consumerism

organisation

Introduction

The Paris Agreement of COP21 confirmed the goal of limiting global temperature increase well below 2 °C and acknowledged the need to achieve net greenhouse gas neutrality during the second half of the century¹. In 2019, 34% of Greenhouse Gas (GHG) emissions came from the energy sector; electricity and heat generation are the largest sub-sector contributing to global GHG emissions^{2,3}. According to the IPCC (2022), a Zero CO2 energy system is possible, but it requires changes in the range of supply-side options, an increasing share of electricity in final energy use, and the potential role of hydrogen, ammonia, etc.

Renewable energy (RE) sources are some of the most important sources of electricity, and the expansion of renewables is one of the central pillars in many countries' energy transition, making them less dependent on imports of fossil fuels. Accounting for CO2e emissions associated with renewable energy is essential to avoid rebound effects (increased consumption) and efficiently implement demand-side solutions in climate change mitigation^{4,5.} Energyrelated information is a common strategy to promote conservation behavior; providing information increases households' awareness of energy consumption, problems, and knowledge about alternatives to reduce consumption^{6,7.} One strategy to promote conservation behavior is linking the so-called climate currency to actual currencies.

We analyze individual consumption based on financial transactions to provide carbon emissions for said transactions, in this case, renewable energy, and thereby create transparency about one's carbon footprint. We then seek to enable financial institutions to turn this knowledge into actionable content to communicate information that helps empower people to change their consumption behavior and thereby reduce their carbon footprint. To transform transaction data into carbon intensity factors (g

CO2eq/currency), we followed the methodology of the open standard framework for consumer carbon calculations based on payment transactions. The carbon intensity factor is a function of carbon emission per renewable energy system and expenditures.

Carbon emissions

RE sources have the potential to reduce greenhouse gas (GHG) emissions from the power sector; however, they are not GHG emission-free. GHG emissions are produced during equipment manufacture, transportation, on-site construction, maintenance, and decommissioning. A life cycle assessment (LCA) is required to estimate GHG emissions. LCA determines environmental burdens from "cradle to grave" and facilitates fair comparisons of energy technologies.

Comparing life cycle stages and proportions of GHG emissions from each stage for each RE system is challenging due to the variability in results among publications. We built on data from the National Renewable Energy Laboratory (NREL), which implemented the Harmonization project, a study that clarifies inconsistent and conflicting GHG emission estimates in the published literature while providing more precise estimates of GHG emissions for RE system⁸⁻¹⁰. The results were later published in the Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change⁹. The study results allow us to compare conventional power generation systems to renewables because it accounts for GHG emissions across the full life cycle of each technology and therefore help inform decision-makers of the attributable environmental impacts of energy technologies¹¹. We obtained grams of carbon dioxide (CO2) equivalent per kilowatt-hour for each stage of the life cycle for photovoltaics (PV), wind, concentrating solar power (CSP), and hydropower RE systems (Figure 1); most emissions are concentrated during the upstream processes. The wind has the lowest emissions, followed by CSP and PV. We



compare emissions associated with coal for the different life cycle stages.

		Life cycle stages		Life cycle GHG	Medium	
Energy system		Upstream processes ^a	Operational ^b	Downstream Processes ^c	emission g CO2eq/kWh	LCOE ^d (in US\$) ^{12,13}
Photovoltaics (PV) ^{8,14,15}	*	~60-70%	~21-26%	~5-20%	~43 g CO2eq/kWh	0.056/kWh
Wind (average for Land-based and offshore wind technologies) ^{8,9,11}	讨	~ 86%	~9%	~5%	~13 g CO2eq/kWh	0.050/kWh (onshore) 0.088/kWh (offshore)
Concentrating Solar Power ^{9,16}	*	~60-70%	~21-26%	~5-20%	~28 g CO2 eq/kWh	0.121/kWh
Hydropower	(J)	~13-39%	~30-60%	~4-20%	~ 21 g CO2 eq/kWh	0.068/kWh (run of river>=5MW) 0.088/kWh (reservoir >=5MW)
Coal ¹⁷		< 1%	>98%	<1%	~1,001 g CO2eq/kWh	0.088/kWh

^a considers raw materials, extraction, module manufacture, parts manufacture, system/plant/farm construction

^b considers power general, plant operation, and maintenance. For coal, it includes coal mining/coal preparation, coal transport, and coal combustion ^c considers system/plant/farm decommissioning. For coal, it includes power plant decommissioning, waste disposal, coal mine land rehabilitation ^d LCOE stands for levelised costs of generating electricity

Figure 1. Comparison of Life cycle GHG emission for photovoltaics, wind, concentrating solar power, hydropower, and coal systems

The GHG emission that will be applied when transforming transaction data to carbon will depend on the country; as mentioned above, RE sources have the potential to reduce greenhouse gas (GHG) emissions from the power sector; however, they are not GHG emission-free. This implies that a third-party verification process should take place for an electricity provider to claim 0 g CO2eq/kWh. For instance, in Germany, the Electricity and Gas Supply (Energy Industry Act - EnWG)¹⁸ requires electricity labeling, which includes information on the environmental impacts, at least in relation to carbon dioxide emissions (CO2 emissions) and radioactive waste, which can be attributed to the total energy carrier mix for electricity generation referred to in number electricity providers to label. Section 42 of the Act states that RE for electricity must be labeled (Figure 2), which guarantees that new systems are promoted using green electricity.



Figure 2. An illustrative example of green electricity labels in Germany

Third-party verification takes place that guarantees that¹⁹:

- 100 percent of the electricity comes from renewable sources: hydropower, biomass, photovoltaics, wind power, geothermal energy, sewage gas
- Contribution to accelerating the energy transition or to the integration of renewable energies into the supply system - in addition to state funding

- no participation of the green electricity provider in nuclear power plants, lignite-fired power plants, and new hard coal-fired power plants
- fair and transparent contract terms

If the energy supplier advertises this electricity as carbon neutral, it must acquire the appropriate certificates, for example, for independently validated and verified reforestation projects, to compensate for the emissions during upstream, operation, and downstream processes (Figure 1). The auditing company reviews if relevant certificates are available or whether the company still needs to take further steps before it can justifiably refer to its electricity as "carbon neutral." If the energy suppliers satisfy all the above, they can report 0 g CO2eq/kWh emissions for their electricity. Caution should be taken since this approach is successful in countries with higher rules of law and voice and accountability²⁰.

In countries where such regulation is not in place, the Life cycle GHG emission per energy system should be used (Figure 1).

Expenditure

Renewable Energy's market price per kWh is used to estimate carbon intensity. The energy costs are those a customer pays the energy supplier for the electricity consumed. The energy costs differ depending on the energy supplier, the network costs, and the taxes prescribed by the federal, state, and local governments.

Prices vary widely, and energy providers are recalculating their tariffs regularly. Thus, countryspecific revision should be performed to compare prices for each type of renewable energy system (i.e., identifying min and max values and regional differences) to make a solid approximation of the market price per kWh. To provide an example, a market price review for wind and solar Energy in Germany was performed based on the comparison portal from the Environmental Association (Vergleichsportal der Umweltverbände) and the green electricity comparison (Ökostromvergleich) from check24. It was impossible to disentangle price differentiation between PV and CSP; therefore, the price shown considers both systems. The market price review showed that the unit price does not change depending on the number of people per household; however, consumption varies, so the consumer pays accordingly.

The reference value for consumption is:

- One person: 1,500 kWh per year
- Two people: 2,400 kWh per year
- Three people: 3,200 kWh per year
- Four people: 3,800 kWh per year

Prices change if consumption exceeds 10,000 kWh per year or 50,000 kWh per year; it varies per electricity provider.



Figure 3. Comparison of market prices among solar, wind, hydropower, and the regular mix for electricity in Germany *Price range, minimum and maximum market price per kWh in Germany

Carbon intensity

Using market price and emissions from RE systems, carbon intensity (CI) is calculated.

$$CI_{RE} = \frac{\text{emission per RE system gCO}_2 \text{eq/kWh}}{\text{price/kWh}}$$

When the source of electricity is from RE solar systems and applying the formula to illustrate the case in Germany, then:

$$CI_{RESOL} = \frac{43 \text{ gCO2eq/kWh}}{0.78 \text{ euro/kWh}} = 55.13 \text{ gCO2eq/euro}$$

Where CI_{RESOL} stands for carbon intensity for solar RE systems, it is important to notice that the estimations are conservative. Therefore, the PV Life cycle GHG emission is used as a based value.

When the source of electricity is from RE wind systems and applying the formula to illustrate the case in Germany, then:

$$CI_{REW} = \frac{13 \text{ gCO2eq/kWh}}{0.75 \text{ euro/kWh}} = 17.33 \text{ gCO}_2 \text{ eq/euro}$$

Where $\mathsf{Cl}_{\mathsf{REW}}$ stands for carbon intensity from wind RE systems.

When the source of electricity is from RE hydropower systems and applying the formula to illustrate the case in Germany, then:

$$CI_{REH} = \frac{21 \text{ gCO2eq/kWh}}{0.5 \text{ euro/kWh}} = 42 \text{ gCO}_2 \text{ eq/euro}$$

Where $\mathsf{CI}_{\mathsf{REH}}$ stands for carbon intensity from hydropower RE systems.

When electricity providers have a green electricity label, which guarantees that electricity is generated from renewable energy sources, appropriate compensation measures for the CO2 emissions have been undertaken, then the CI_{RE} is:

$$CI_{RE} = \frac{0 \text{ gCO2eq/kWh}}{\text{price/kWh}} = 0 \text{ gCO}_2 \text{ eq/euro}$$

As a reference, the carbon intensity factor for the regular mix (of fossil fuels (coal, oil, natural gas)) is 427 gCO2eq/euro.

$$CI_{REM} = \frac{203 \text{ gCO}_2\text{eq/kWh}}{0.475 \text{ /kWh}} = 427 \text{ gCO}_2\text{eq/euro}$$

Key takeaways

- Renewable energy systems are not GHG free.
- The substitution of fossil energy carriers for renewables and the resulting adjustment needs in the power generation system are at the core of climate and resource efficiency policies.
- Carbon intensity for solar systems is 55.13 gCO₂eq/euro.
- Carbon intensity for wind systems is 17.33 gCO₂eq/euro.
- Carbon intensity for hydropower systems is 42 gCO₂eq/euro.

Glossary^{9,22}

Green Energy refers to the energy that is 100% produced from renewable energy.

Renewable energy sources also called renewables, are energy sources that replenish (or renew) themselves naturally. Typical examples are solar energy, wind, and biomass²².

The rebound effect describes the phenomenon that when energy efficiency is increased, the consequent reductions in energy consumption are lower than engineering calculations predict due to increases in demand²³.

Life cycle assessment (LCA) is a systematic tool that allows for the analysis of environmental loads of a product in its entire life cycle and the assessment of their potential impacts on the environment.

Solar Energy: solar thermal energy (radiation exploited for solar heat) and solar photovoltaic for electricity production. In other words, it is the conversion of sunlight into electrical energy using photovoltaic (PV) panels or solar radiationconcentrating mirrors.

A watt is a unit of power or a rate of energy flow. 1 TW = 1,000 GW = 1,000,000 MW = 1,000,000,000 kW.

A kilowatt-hour is a unit of energy. 1 kWh is the electrical energy required to light a 100-watt light bulb for 10 hours.

Wind energy: the kinetic energy of wind converted into electricity in wind turbines.

Zero energy systems, we use the analysis by the IPCC (2020)³ who defines net-zero energy systems those that produce very little or no CO2 emissions. While energy systems may not reach net zero concurrently with economy-wide CO2 or GHG emissions, they are a useful benchmark for planning a path to net zero.

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Transaction to Carbon

An open standard for consumer carbon calculations based on payment transactions.

Technology is a tool for changing the world, but only by putting people at the centre of that tool can its use be truly transformative, changing the person. Hence, the changes in making the world more liveable are sustainable.

